Game Physics – Programming Exercise

Exercise 2 – *Rigid Bodies*

Task Overview

First take pen and paper, and manually calculate one time step for a single moving rigid body (setup in Table 2.1) with the Euler method.

Then, **download the gamephysexercise.zip from moodle page**. Based on the given header file, please implement your simulator for 3D rigid body systems. Set up the test case in Table 2.1, and check the one-step results with your manually calculated results.

Afterwards, implement **collision detection** and **collision response** methods. Set up a two-box scene to show a corner to face collision between them. Finally, show off your system with multiple rigid bodies and interactive external forces and collisions.

Details of the things you need to submit (the deliverables) are listed below.

Table 2.1, A single rigid box scene

Box center:$\mathbf{(0,0,0)^T}$, size:**(1, 0.6, 0.5)**, mass: **2**,

initial orientation: **rotated around Z by 90 degrees**

Simulate the rigid body for 1 step with an external force $\mathbf{f} = \mathbf{(1,1,0)^T}$ applied at world space position $\mathbf{(0.3, 0.5, 0.25)^T}$. Compute resulting linear and angular velocity, and the world space velocity of point $\mathbf{(-0.3, -0.5, -0.25)^T}$.

Recommendations & Tips:

1. **Orientation**. Use quaternions to represent the orientation of the rigid bodies
2. **Integration.** Use explicit Euler integration in time. Refer to the “Simulation Algorithm 3D” from the rigid body lecture slides.
3. **Quaternions.** The update rule for the rigid body orientation does not conserve unit length. Don’t forget to re-normalize the quaternions manually after each update. Also remember that you can always convert back and forth between rotation matrices and quaternions. E.g. it is easier to specify a given rotation as a matrix, and for rendering you should also use the matrix representation. (A nice way to debug quaternions is applying their corresponding rotation matrices to simple objects,

such as a long box, and rendering them, since quaternions are hard to interpret by inspecting the raw vector values. In this way you can visualize the rotation they cause.)

4. **Inertia Tensors.** Analytic formulas for inertia tensors of common objects like boxes or spheres can be found online, e.g. at http://en.wikipedia.org/wiki/List_of_moment_of_inertia_tensors.
5. **Interaction**. You can add extra forces, e.g. by dragging the mouse. Gravity forces may not be used for Demos 1 to 3, and are optional for Demo 4.
6. **Collision Detection**. You can find a simple function for collision detection on the moodle page (collisionDetect.h). On the **last page** of this exercise (p. 5), you can find an explanation of that function. In this function, the separating axis theorem is used to check whether two boxes A and B are overlapped. If an overlap occurs, one collision point and one collision normal will be returned. It is a simple detection method, and only return one collision point. The limitations of this method are also explained on the last page.
7. **Render a Rigid box**. You can use the following lines to draw a rigid box.

   DUC->setUpLighting(...); // set the lightings, like in the mass spring exercise

   DUC->drawRigidBody(GamePhysics::Mat4 transformation);

   //input matrix is the transfer matrix from object space of the box to the world space

   Here is an example.

   DUC->setUpLighting(Vec3(0,0,0),0.4*Vec3(1,1,1),2000.0, Vec3(0.5,0.5,0.5));

   BodyA.Obj2WorldMatrix = BodyA.scaleMat * BodyA.rotMat * BodyA.translatMat;

   DUC->drawRigidBody(BodyA.Obj2WorldMatrix);
8. **Left handedness**. In order to work with DirectX, our matrix class works with left handedness. That means we use row major matrices, row vectors and pre-multiplication. For e.g., if you want to transform a vector, you should call v = Mat.transformVector(v). This will do the calculation of v = v * Mat . You will get wrong result if you do v = Mat * v. For another example, the object to world matrix should be scaleMat * rotMat * translationMat, instead of the other way around (translationMat * rotMat * scaleMat). Quaternions have no handedness, but they can be transferred into row-major (left handed) matrices or column-major (right handed) ones. Our Quat::getRotMat() will give you the left handed matrix. Please use the new matrix.h file (in the \gamephysexercise.zip file). In the old version, the "initRotationX/Y/Z" functions worked according to the right handedness. In the new version, they are fixed.
9. **Tests.** Try the given tests in "PublicRigidBodiesTests.cpp" file with:
   - Visual Studio -> TEST -> Run -> All Tests
   - Visual Studio -> TEST -> Windows -> Test Explorer
   - Double click on the test cases to see details. Right click to run or debug on a particular test.
   - If you get some platform errors, try Visual Studio -> TEST -> Test settings -> Default Processor Architecture

These tests are designed to make sure that your simulator is working correctly. However, they are still somewhat experimental. Different, mostly correct implementations can still yield failed tests. You don't have to pass all tests to pass the exercise. It would be very helpful for us if you can report to our tutors, when you feel your codes are right but fail to pass these tests.

Demo requirements:

Your submission should contain the following demos and should support **interactive switching between these demos**:

- **Demo 1, a simple one-step test:**
  - Manually calculate the solution to the single rigid box setup above, with the parameters given there (no need to submit this), for an Euler time step of size h=2.
  - Download the gamephysexercise.zip file from moodle page. Extract it under your source folder and replace existed files (matrix.h file is updated).
  - According to the class definition in "RigidBodySystemSimulator.h" file, implement your "RigidBodySystemSimulator" class to compute a solution for the same problem with your simulator.
  - The following steps are necessary to add the rigid bodies to the Visual Studio project: In Visual Studio, set the "simulationsRunner" as the startup project. In main.cpp, replace "#define TEMPLATE_DEMO" with "#define RIGID_BODY_SYSTEM" at line 23. Add the "PublicRigidBodiesTests.cpp" file into the "SimulationsTester" project. Then you can run and test your RigidBodySystemSimulator class.
  - Build and run the basic test case, and print your solution (i.e., linear and angular velocity of the body and the world space velocity of point $(0.3, 0.5, 0.25)^T$) after one time step to the command line. Verify your manual calculation.

- **Demo 2: a simple single body simulation (sample video on moodle page):**
  - Simulate the single rigid body with smaller time step h = 0.01, for multiple steps.
  - Add extra forces on the body through mouse or keyboard, and display the simulation interactively for longer times. Verify as much as possible that it gives the correct behavior.

- **Demo 3: a two-rigid-body collision scene (sample video on moodle page):**
  - Set up an own scene with two rigid body boxes. Their initial linear velocities (no angular velocities) should make them collide. Make sure that, only one rigid body's corner will collide the other one on its face.
  - Manually calculate your collision test case by hand (Choose a test case with simple values!) Calculate the world position of the collision point, the normal of the collision face, the velocity difference between the two boxes at the collision point in world space, and the impulse J. Update the velocity and momentum of the two boxes according to J as described in the slides.

- Add support for collision in your simulator. Use the given collision detection function to check if there is a collision. Based on the returned data, implement your collision response method by calculating the impulse and updating the momentums.
- Run your two-box collision scene and validate it with your calculation. You do not have to submit your manual calculation. Your demo should show the two body colliding, and separating correctly after collision.

- **Demo 4: a complex simulation:**
  - Set-up a simulation with at least 4 boxes.
  - Provide methods for interaction, e.g. by including extra forces. You can also add a ground floor (or walls) and enable gravity so that all rigid bodies will collide with it. (Note that bodies will not fully come to rest with this basic simulation algorithm.)

Deliverables

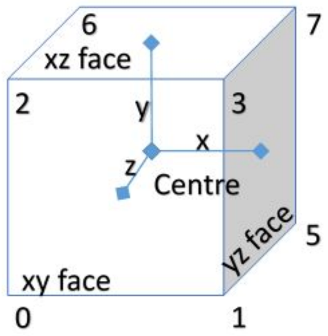
The deadline for this exercise is on **Dec. 4, 23:59**.

If you are using Bitbucket/GitHub, please send your repository link to your tutor, and make sure that our tutor has the permission accessing it. If you already shared the repository with your tutor, a notification email before the deadline is still necessary, pointing out which commit the tutor should use as your final version.

If you are not using Bitbucket/GitHub, please pack all your source files (.h and .cpp) and project files (.vcxproj) under the "Simulations" directory into a zip file, and name it "Group??_Ex2_VS201?.zip", and sent it to your tutor. Make sure not to include the compiler temporary files (they will be under the Simulations/Win32/ directory). Your package should be smaller than 100kb.

Collision Detection in 3D for boxes AB

- The method in collisionDetect.h:




```
CollisionInfo checkCollisionSAT (Mat4& obj2World_A,
Mat4& obj2World_B)
```

This method checks if A and B are overlapped using the Separating Axis Theorem.
obj2World_A, obj2World_B, are the transfer matrix from object space of A/B to the world space, including the rotation, the scaling and the translation.

- Data returned by the method:

```
struct CollisionInfo{
        bool    isValid;
        Vec3    collisionPointWorld;
        Vec3    normalWorld;
        float   depth;
}
```

- **isValid: whether a collision was found, true for yes**
- **collisionPointWorld : the position of the collision point (one vertex of B) in world space**
- **normalWorld: n, the normalized direction of the impulse from B to A. For e.g., when one vertex of B is knocked into a face of A, the n will be negative of the face normal of that collision face.**
- **depth: how far the collision point is inside A. It is a redundant value which should not be used in your impulse calculation**
- **If no collision is detected, the method will return {false, Vec3(0.0), Vec3(0.0), 0.0}.**

- Once you find a collision, your collision response function should calculate:
  - **v_{rel}, the relative velocity between A and B at the collision point (in world space).**
  - **If $v_{rel} \cdot n > 0$, this indicates that the bodies are separating.**
  - **Otherwise continue to calculate the impulse J, and apply it to both bodies.**

- A simple example function, “testCheckCollision”, can be found at the end of collisionDetect.h

- Limitations:

When checking collision on edges, edges are discretized into several points. Therefore, edge to edge collisions may be slow and not fully accurate.